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Past, present, and future low carbon supply chain management: A content review using social network analysis

Muhammad Shabir Shaharudin [a], Yudi Fernando [a, b], Charbel Jose Chiappetta Jabbour [c], Robert Sroufe [d, *], Muhamad Fairuz Ahmad Jasmi [a]

[a] Faculty of Industrial Management, Universiti Malaysia Pahang, 26300, Pahang, Malaysia
[b] Management Department, BINUS Online Learning, Bina Nusantara University, 11530, Indonesia
[c] Montpellier Business School, International Center of Research and Education, Montpellier, France
[d] Duquesne University, 820 Rockwell Hall, 600 Forbes Avenue, Pittsburgh, PA, USA

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ABSTRACT

The aim of this study is to identify the past, present, and future research trends for low carbon supply chain (LCSC) management. The literature on low carbon supply chain management has expanded, however, a systematic review of lessons learned and future research opportunities is necessary. We do this using a review of the literature and social network analysis. The data for this study consists of English articles published by multiple databases found through the Web of Science and Scopus. We reviewed, collected, and sorted articles from 124,793 publications and then identified 2199 as being relevant to the scope of work for this study. Next, we utilized a social network analysis of the data. The results uncovered six main domains of LCSC: sustainability, climate change, green supply chain management, supply chain management, innovation, sustainable development, and environmental management. Contributions of this study include the development of these domains along with several important themes. The insights uncovered by our analysis primarily focus on LCSC modelling, low carbon energy, and carbon emission measurements. Numerous sustainability management practices are associated with low carbon energy use and actions to avoid increasing the rate of climate change. Paradoxically, we find limited evidence in the literature on how the LCSC practices can achieve integrated levels of performance that should also include carbon performance indicators.

1. Introduction

Business trends over the last two centuries and continued population growth has triggered the clearing of lands for agriculture, development, manufacturing facilities, and supply chain infrastructure. Because of this continued expansion, global environmental problems have become challenging operations issues (Fernando et al., 2018a). Why are global environmental problems important to operations? Because manufacturing firms and their supply chains are considered to be the most significant contributors to carbon emissions. For example, deforestation exists because of uncontrolled output of agriculture products (Huisingh et al., 2015), the overuse of burning coal for fuel (Aguirre-Villegas and Benson, 2017), and the supply chain activities of global firms (Camanzi et al., 2017). As we now know that over 90 percent of emissions can be found in the supply chains of firms (Mao et al., 2016a), the overuse of fossil fuel for energy to support transportation and production has more recently enabled the adoption of Low Carbon Supply Chain (LCSC) practices throughout firms' supply chain activities and networks.

For the purpose of this study, LCSC can be defined as a strategic, environmentally-aligned initiative that aims to achieve operational excellence and cost reductions by focusing on energy efficiency and reducing carbon emissions. We find this is operationalized throughout four important domains of supply chain activities, including: procurement, production process, product, and logistics. To help ensure successful LCSC, firms must communicate, share, collaborate, and integrate their business process with supply chain networks to respond to market demand while making fast, accurate

* Corresponding author.
E-mail addresses: shabir.shaharudin@gmail.com (M.S. Shaharudin), yudhitjoa@gmail.com, yudi.fernando@binus.ac.id (Y. Fernando), cjcjabbour@gmail.com (C.J. Chiappetta Jabbour), sroufer@duq.edu (R. Sroufe), fairuzjasmi89@gmail.com (M.F.A. Jasmi).

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business decisions (Sroufe, 2018).

This study reviews and conceptualizes research in supply chain management with a focus on greenhouse gas emissions. With a specific focus on carbon emissions, i.e., carbon dioxide, we attempt to provide new insights on the relevance of this topic and its use as a measure of performance. Carbon emissions trap heat and remain in the atmosphere for more than 100 years (Juniper, 2007). If increasing carbon emissions are not offset by other practices that reduce emissions, a "point of no return" will be reached that will impact a firm's ability to achieve economic, operational, and environmental performance outcomes, while society suffers the negative impacts of unsustainable business practices. For example, customers' requirements will become more complex due to the demand for low carbon products (Hoejmose et al., 2014) and regulations for business will become more stringent in trying to combat climate change (Zu et al., 2018). Additional investments in green technology are required to run low carbon production (Fernando et al., 2016) and to meet the rise of influential environmental non-governmental organizations (NGOs) that impact firms' operations (Rodríguez et al., 2016). In advance of these predictions, we already see stakeholders recommending that firms reduce carbon emissions in their daily operations.

The concept of LCSC originates from environmentally responsible supply chain management and operations, with a purposeful focus on reducing carbon emission. In this study, the conceptual development of the LCSC integrates perspectives gathered across multiple disciplines. The literature in this field is rapidly expanding (Wang et al., 2017). This quick expansion has led to some inconclusive results of LCSC and created room for debate regarding impacts on performance. This field of research attracts scholars from different schools of thought including management science and technical/engineering to conceptualize and operationalize the LCSC paradigm. Management-approach scholars have mostly focused on how carbon emissions data can be interpreted to articulate business strategies to reduce carbon emission, while technical-approach scholars look at how to reduce carbon emissions using mathematical perspectives.

Although LCSC has been discussed widely in the literature, further research on low carbon practices is necessary, as comprehensive theories have not yet been developed (Reefke and Sundaram, 2017). Scholars have begun to investigate requirements for firms to practice LCSC to foster a more efficient adoption of low carbon practices (Luo et al., 2017). Nevertheless, LCSC studies have remained limited to exploring drivers of LCSC practices (Yu et al., 2015), measurement constructs (Hu et al., 2017), and underlying theory (Carter and Liane Easton, 2011; Reefke and Sundaram, 2017; Winter and Knemeyer, 2013). Despite these efforts, a systematic understanding of rigorous practices, measurement options, and LCSC theory development still remains limited. This study fills that research gap.

Using a proven content review technique, the information presented in this study aims to provide direction for LCSC studies to address the afore mentioned issues and contribute to conceptualizing a new theoretical understanding of LCSC. In this study, content analysis involves analyzing bibliographic information and the co-occurrence of keywords. This type of analysis provides for a dynamic discussion on current trends and the theoretical understanding of LCSC, while also uncovering gaps in the literature scholars may bridge and shedding new light on LCSC practices. The main contribution of this study is a wide-ranging analysis of LCSC literature in the journal databases from the beginning of its availability until the present. Due to the high number of articles related to this topic, it is important to the development of the field to provide analytical trends, identify gaps in the literature, and develop future research opportunities worthy of investigation by scholars. To do so, the researchers in this study used bibliometric analysis for LCSC scholarly articles as applied to bibliographic information from databases. The outcomes reveal current trends, gaps in the literature, and a visual picture of the evolution of this field of research (Aznar-Sánchez et al., 2018).

To help understand the burgeoning field of LCSC and to provide new insights from a bibliometric synthesis of publications, the information in this study attempts to answer the following primary research questions:

- Q1 What are the main themes regarding LCSC, specifically for business and management fields? This research question can be relevant to understanding both dominant topics and gaps in the body of knowledge on LCSC.
- Q2 What is LCSC management and which journal(s) provide(s) the most significant conceptualisation of this paradigm? This question provides an understanding of the most important publication outlets for LCSC, and therefore allows stakeholders interested in LCSC to monitor the latest developments in the topic.
- Q3 What is the country of origin for scholars who have published on LCSC? Insights from this question will make it possible to see whether the knowledge on this topic is widespread in both emerging and mature country economies. If most of the studies on LCSC focus on developed countries, more research on the challenges and opportunities of emerging countries will provide opportunities for further research and application.
- Q4 What are the highest LCSC co-occurrence words used in the business and management fields, as well as across fields of study? This point allows for an understanding of the most frequently used terms in LCSC and its key-components, which are relevant to stakeholders as they must establish a common language in order to move LCSC research forward.
- Q5 What is the past, current and future trajectory of LCSC studies? The response to this question can provide a research agenda, which will be useful for developing the topic further.

Based on a review of the literature, it is possible to suggest that this study extends the current literature on sustainable supply chain management, as there is a dearth of similar work purposefully focusing on low carbon strategies while also addressing all five primary research questions. All of the LCSC reviews found on Scopus (de de Sousa Jabbour et al., 2018; Deris et al., 2017; Xia et al., 2013; Chelly et al., 2018; Das and Jharkharia, 2018) differ from this study. The uniqueness of this study emerges when the insights are compared to other literature review papers on LCSC. First, there are works (de Sousa Jabbour et al., 2018) in the literature which focus on a wide number of low carbon operations management practices rather than exclusively focusing on LCSC management. Our study builds upon and contributes to research on supply chain management. There are also works focusing on a specific LCSC practices such as low carbon freight services analysis, i.e., a more narrowed perspective on the topic (Deris et al., 2017). The literature contains reviews on LCSC (Xia et al., 2013; Chelly et al., 2018) which focus exclusively on quantitative and modelling approaches to lowering emissions across supply chains. Our work in this study provides new contributions to the field of supply chain management as it extends and provides new insights to prior literature reviews on LCSC practices (Das and Jharkharia, 2018), such as low carbon inventory control, transportation planning, facility allocation, location selection, and supply chain coordination. To conclude, this article presents comprehensive research, which encompasses the tools applied and the results achieved by LCSC activities, which remains a missing topic in the current literature.

2. Low carbon supply chain (LCSC)

Building on the work of Böttcher and Müller (2015), it is possible to extend the definition of low carbon operations and define LCSC as the reduction of carbon emissions in the operations of product development, production process, and logistics. In addition, Fernando and Hor (2017) defined LCSC as the reduction of carbon emissions in terms of per unit revenue, operations, fees for carbon discharge, production process, and overall emissions. Two schools of thought exist with respect to LCSCs. The first school of thought defines LCSC as different from Green Supply Chain Management (GSCM) due to LCSC's goal of reducing greenhouse gas (GHGs) emissions, the strong correlation to energy, and the voluntary reduction of carbon emissions (Jassim et al., 2017; Mujica et al., 2016; Nishitani et al., 2013). The second school of thought defines LCSC as an extension of GSCM that indirectly helps firms to achieve a reduction in carbon emissions (Das and Jharkharia, 2018; Kushwaha and Sharma, 2016). Taking into consideration both schools of thought, this study conceptualizes LCSC as the design, control, monitoring, and reduction of carbon emissions along the supply chain, including product design, procurement, production process, and logistics that include distribution networks. Table 1 shows some of the relevant literature on carbon emissions reduction throughout the supply chain that are inconsistent with GSCM practices. Table 1 also shows that LCSC focuses on energy and material-related issues as well as carbon emissions reduction. Therefore, this study adopts the position that the conceptualization of LCSC is more inclined towards the first school of thought, in which LCSC is regarded as a special type of GSCM.

Indeed, nuances of GSCM exist in the attributes of LCSC that include but are not limited to the measurement of overall firm level carbon emissions, energy use, and subsequent emissions, along with carbon intensive materials in the product (Böttcher and Müller, 2015), fees paid for fines and taxes for firms to discharge carbon emissions, production processes, and operations (Fernando and Hor, 2017). GSCM has broad features such as pollution/waste reduction, general environmental regulation compliance, environmental reputation of the firm, and overall environmental performance of the firm (de Sousa Jabbour et al., 2015). In the context of GSCM, the conventional economic perspective shifts to that of a green economy, which also drives manufacturing firms to re-align their business strategies toward low carbon performance. Therefore, firms should not only pursue profitability but should also pursue the integration of broader sustainability performance (Fernando et al., 2018b; Sroufe, 2017). In this context, manufacturing firms can practice green operations, focus on sustainability activities, and make efforts to achieve lower costs, improve the quality of products, enhance stakeholders' well-being and realize a lower carbon footprint (Fernando et al., 2017).

As shown in Fig. 1, we propose a conceptual model of LCSC based on our own insights and a review of the relevant literature. LCSC objectives include reducing carbon emissions and maintaining control throughout the supply chain process from procurement, product design, production process, and distribution to logistics. Each supply chain process that emits carbon emissions presents an opportunity for reduction through proper management of carbon emissions. Firms are now able to reduce carbon emissions in procurement activities with suppliers through purchasing low carbon energy and/or renewable energy options (Clarke et al., 2017), purchasing low carbon materials (Nakajima et al., 2013), and purchasing low carbon goods and services (Correia et al., 2013). When firms acquire suppliers of low carbon energy, low carbon materials, and low carbon goods or services, they can begin designing and developing their products. Some firms collaborate to integrate suppliers and customers during product design to reduce carbon emissions at the design stage (Mao et al., 2016). During the design stage firms can reduce carbon emissions by substituting traditional materials with renewable and recycled materials and by using low carbon materials. Additionally, through the application of life cycle assessment, firms can discover new insights into materials and product life cycles (Böttcher and Müller, 2015). Once the design phase is complete, firms can manufacture the product. The manufacturing stage is one of the largest contributors to carbon emissions (Huisingh et al., 2015; Ishak and Hashim, 2015). Firms can reduce carbon emissions at this stage by using low carbon energy, such as renewable energy. They can also invest in energy conservation and efficiency projects (Fernando et al., 2018), invest in low carbon technology and machinery (Aljazzar et al., 2018), utilize low carbon materials, and conduct life cycle assessments to control carbon emissions (García-Durañona et al., 2016). Finally, firms can also reduce carbon emissions by using environmentally friendly packaging to indirectly lower emissions and environmental degradation (Beitzen-Heineke et al., 2017).

After manufacturing, finished products are typically held in reserve at a warehouse or distributed to a supply chain network. We find growing attention given to carbon emissions at this stage. From the literature we know that firms are concerned with carbon emissions related to storing inventory in warehouses (Chen et al., 2016). From the warehouse, firms transfer the product to the customer. We know that lowering carbon emissions related to transportation throughout a supply chain is a concern to both firms and customers. With a focus on low carbon options for logistics,

Table 1
LCSC practices

Domains	Practices	Authors
Low carbon **procurement**	Reducing carbon emissions through purchasing of low carbon energy supply, consumption and purchasing of goods and services that reduced overall life cycle carbon emissions.	Correia et al. (2013)
Low carbon **product design**	Consideration of life cycle assessment during product development, using renewable and recycled materials, reducing carbon intensive materials and overall emissions	Böttcher & Müller (2015)
Low carbon **production process**	A carbon emissions reduction practice through integration of energy related concerns, technology and machinery adoption, materials and parts choices and managing life cycle and process in production	Jin et al. (2017)
Low carbon **distribution**	The warehousing and movement of goods using less energy, low carbon emissions and environmental packaging.	Chen et al. (2016)
Low carbon **logistics**	A carbon emissions reduction in regards to transportation efficiency, technology emission and productivity.	He et al. (2017)

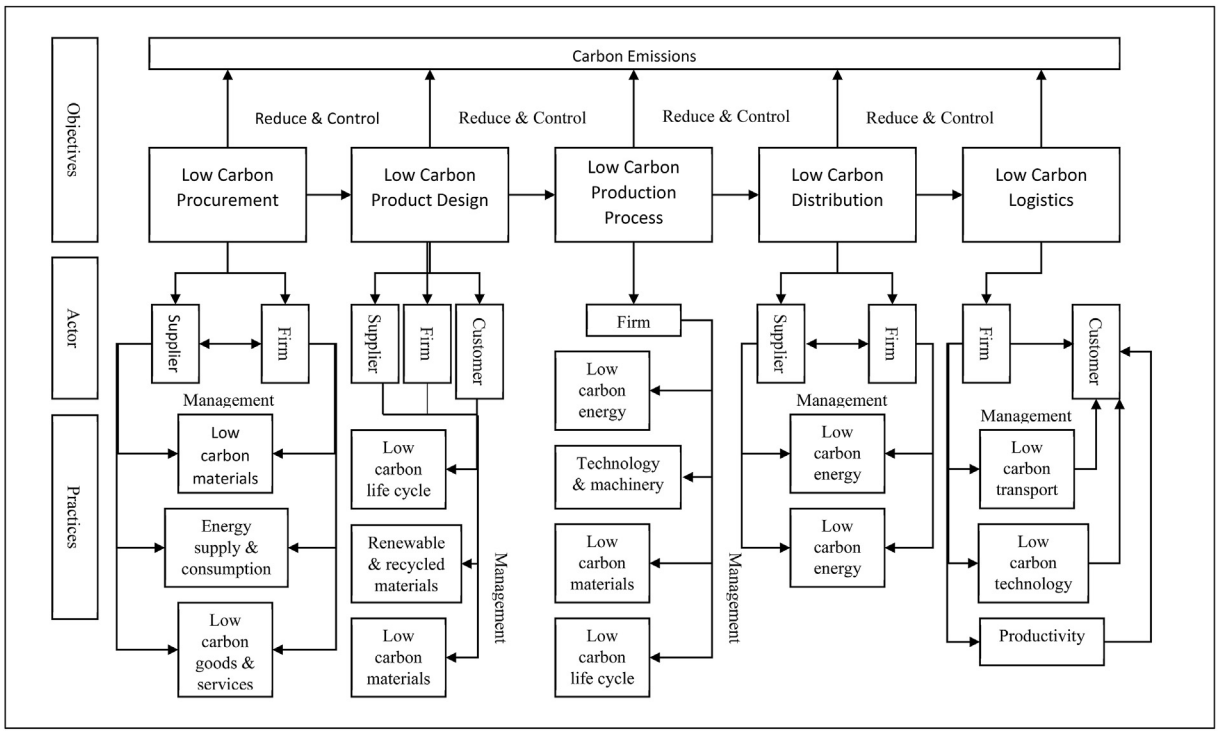


Fig. 1. Low carbon supply chain conceptual mode.

firms can reduce transportation carbon emissions (Lee et al., 2017). Additionally, firms can invest in low carbon technology to help design transportation routes (Li et al., 2016) and consolidate shipments (Kellner and Igl, 2015). These are some of the primary practices of LCSC throughout supply chain processes that focus on carbon emissions reduction and control.

LCSC practices as illustrated in the proposed conceptual model are built upon a foundation of organizational theory. The supply chain management field has only recently adopted organizational theory (Sarkis et al., 2011), as supply chain management is a multi-disciplinary field (Ketchen and Hult, 2007) that combines supply chain and operations (management) with environmental studies (science). Studies on LCSC show the application of the following theoretical foundations. Theory in the LCSC literature includes the use of:

- Institutional Theory, to investigate institutional pressure on firms to practice LCSC (Zeng et al., 2016);
- Stakeholder Theory, to investigate the drivers of LCSC (Böttcher and Müller, 2015);
- Contingency Theory, on how firms can anticipate and improve risk management for LCSC (Furlan Matos Alves et al., 2017);
- the Resource-based View, for firms capabilities in practicing LCSC to remain competitive (Fernando et al., 2018b);
- the Natural Resource-based View, for firms to achieve performance through capabilities reliant on green development (Mao et al., 2016b) theory;
- as well as Game Theory, for strategy selection for firms to achieve low carbon performance (Chen et al., 2017).

3. Methods

Utilizing a bibliometric procedure and analysis proposed by Wang et al. (2017) and Ahi et al. (2016), this study addresses all of the primary research questions included in the introduction section. This study improves the reliability of the findings of prior studies by including additional parameters and increasing the volume of publications available on two leading databases (Web of Science and Scopus). We excluded books from this study using a keyword filter for searching journal articles. In order to strengthen the theoretical understanding of LCSCs and so that we did not limit the study to sustainability and environmental management disciplines exclusively, we also included a science discipline/perspective. Our methods led us to use Elsevier/ScienceDirect and Emerald as the main resources of this information. These databases are popular and widely available for scholars in environmental management and green related multi-disciplinary studies. Furthermore, this study did not filter by publication year as we were concerned it could jeopardize the content analysis. Table 1 shows the research procedure of content analysis. We discuss the details of procedure in the following subsections involving an overview of content analysis, social network analysis, and the research process for operationalizing the stages and steps involved in our methods.

3.1. Content analysis

Content analysis defines the parameters based on the occurrence of keywords that appear in a text. The core content of literature can be identified by analysing the frequency of keywords used in the text (Du et al., 2014). A keyword is a critical aspect of content analysis. Thus, the approach taken in this study was to use low carbon supply chain and the acronym of LCSC as a keyword to distinguish parameters in databases. This produces the most accurate and desirable results while screening out other undesirable outcomes. Selecting the keyword of LCSC in three leading databases to analyse the data provided a sufficient indicator to determine whether the selected databases were relevant to LCSC studies. Furthermore, through bibliographic information, we were able to identify which database provides greater search accuracy and

contributions to LCSC literature.

Providing only keyword frequency analysis or bibliographic analysis can be insufficient for a multi-disciplinary study (Wang et al., 2017). The fields of environmental management and supply chain management are complex when investigating LCSC. For example, carbon emissions, bio fuel, and energy efficiency are complex environmental management issues, while risk, tourism, and cyber security are issues specific to supply chain management. Therefore, studying the correlation of the co-occurrence of a keyword to identify word clusters is recommended by Wang et al. (2017). After reviewing the strengths and weaknesses of content analysis by occurrence of keywords, the methods used for these types of studies propose using social network analysis as an additional tool to analyse, understand, and find thematic information regarding the topic under investigation. Next, we discuss the importance of social network analysis with VOSviewer software before taking a more detailed look at the stages and steps involved in the full content analysis approach applied in this study and the use of Mendeley software.

3.2. Social network analysis

The approach presented in this study is well suited for bibliometric clustering and conceptual model development. The software tools utilized in this study are accessible for free and can be used by anyone (specially aspiring scholars) to determine current trends and gaps in the published literature and databases. The advantage of using free access tools such as Mendeley and VOSviewer is that it allows for the clustering of publications without advanced computer skills or profound knowledge of clustering techniques. For example, data downloads from the journal databases can be directly uploaded to the software tools without the need to preprocess the data, provided that there is no data duplication. Mendeley was used to filter the data for this research as it is the most efficient tool for preventing data duplication. However, despite the ease of use of both Mendeley and VOSviewer, a general understanding of clustering techniques is recommended to execute consequential analyses and to aid in the interpretation of the obtained results.

Social Network Analysis (SNA) identifies word clusters based on a co-occurrence keyword (Lee et al., 2017). SNA is a two-part method. The first part represents social actors (Zou et al., 2017) and the second part represents the interconnection between scholars (Lee et al., 2014). In that sense, SNA enables the methods used in this study to identify LCSC topics, investigate the country of origin of scholars, and identify the most frequently cited journals. In this study we enabled SNA using a software called VOSviewer version 1.6.7 (Perianes-Rodriguez et al., 2016). VOSviewer is used to perform bibliographic analysis and is able to provide word frequency analysis using the method of co-occurrence-based keywords. The software applies normalization, mapping, and clustering techniques and provides opportunities for data visualization. This software relies on the Apache OpenNLP toolkit to perform part-of-speech tagging (i.e., to identify verbs, nouns, adjectives). It then uses a linguistic filter to identify noun phrases. The filter selects all word sequences that consist exclusively of nouns and adjectives and that end with a noun. Some noun phrases are very general, and one usually does not want these noun phrases to be included in one's co-occurrence network. VOSviewer therefore calculates for each noun phrase a relevance score and relevant terms in the domain of interest. The visualization functionality of the software then displays researchers as circles with the size of the circles representing the amount of publications. In general, the closer two researchers are located, the more strongly they are related to each other and have a tendency to cite the same publications. Different colors indicate clusters of researchers that are more strongly related to each other (Perianes-Rodriguez et al., 2016).

3.3. Research process

This study extends the results of the work completed by previous scholars relevant to the field of LCSC (Ahi et al., 2016; Wang et al., 2017; Zou et al., 2017). Table 2 summarizes the stages followed to conduct the content analysis used in this paper. First, we divide this process in multiple stages. Stage 1 involved performing research to find all LCSC publications regardless of the field of study. LCSC publications were extracted from databases over a timespan from the beginning of its availability until 2018. The ScienceDirect database search covered the years 1995–2018 while Emerald covered 1989 to 2018. Finally, the Web of Science covered the years 2000–2018. Next in this stage, we narrowed the focus of LCSC publications in the area of sustainability, business management, and environmental management sciences. We feel this will be helpful to future researchers performing similar studies and for replication of our resulting sample set. For Stage #1, we selected three sets of data from leading scholarly databases, namely, ScienceDirect and Emerald covered under Web of Science and Scopus.

Table 2
Research process

Stage#	All LCSC Field	Business & Management Field
Stage 1 Publications from Databases	*Step 1: Select Database* i. ScienceDirect 122,718 ii. Emerald 2075 iv. Web of Science 727 *Step 2: Filter* i. LCSC keyword only ii. No book publications TOTAL 124,793 Publications	*Step 1: Select Database* i. ScienceDirect 1418 iii. Emerald 1519 iv. Web of Science 306 *Step 2: Filter* i. LCSC keyword only ii. No book publications TOTAL 2199 Publications
Stage 2 Check for Duplicates	*Step 1: Filter in Mendeley*	*Step 1: Filter in Database* *Step 2: Filter in Mendeley*
Stage 3 Content Analysis	*Step 1: Co-occurrence analysis* *Step 2: Bibliographic* *Coupling Analysis*	*Step 1: Co-occurrence Analysis*
Stage 4 Discussion	*Step 1: Identify key findings* *Step 2: Answer all research questions* *Step 3: Identify literature gap & future research*	

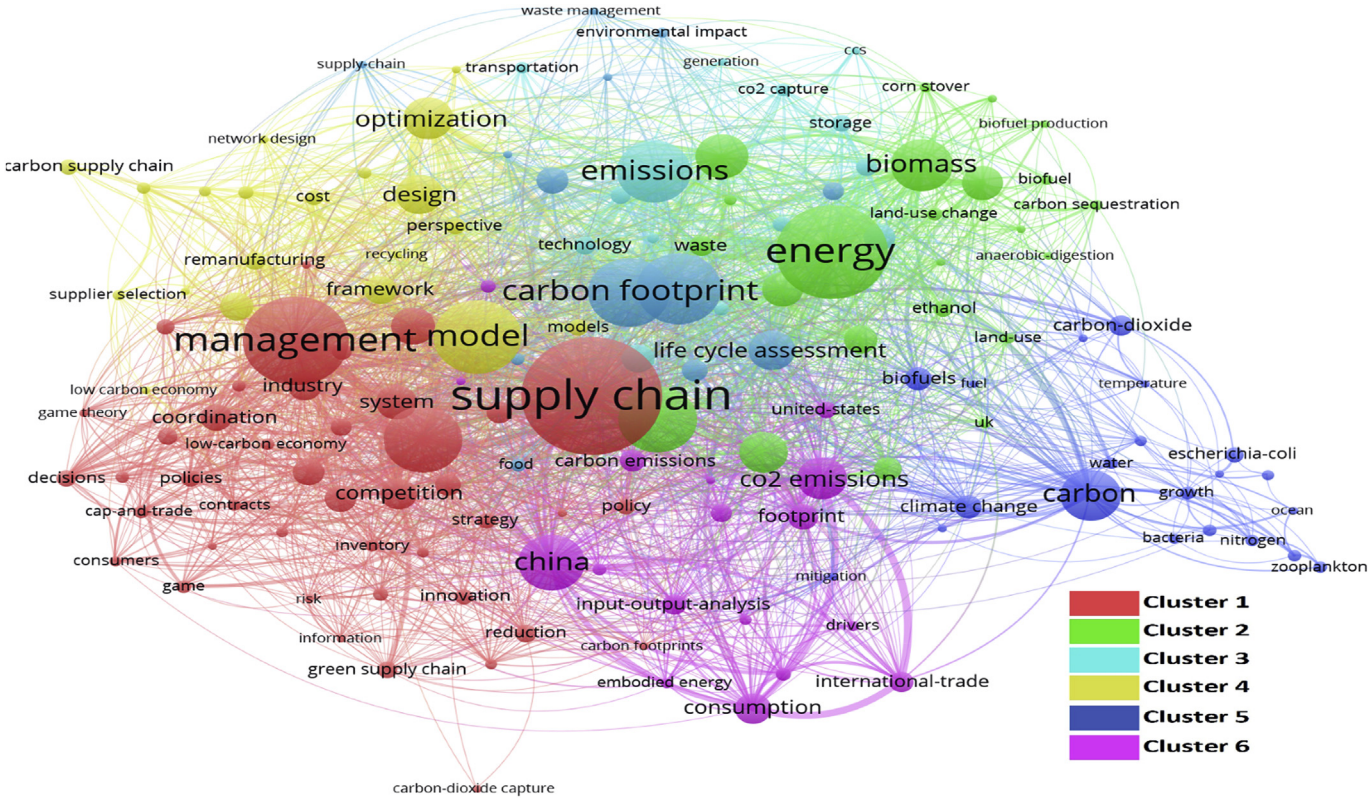


Fig. 2. Network visualization occurrences - full keywords all fields.

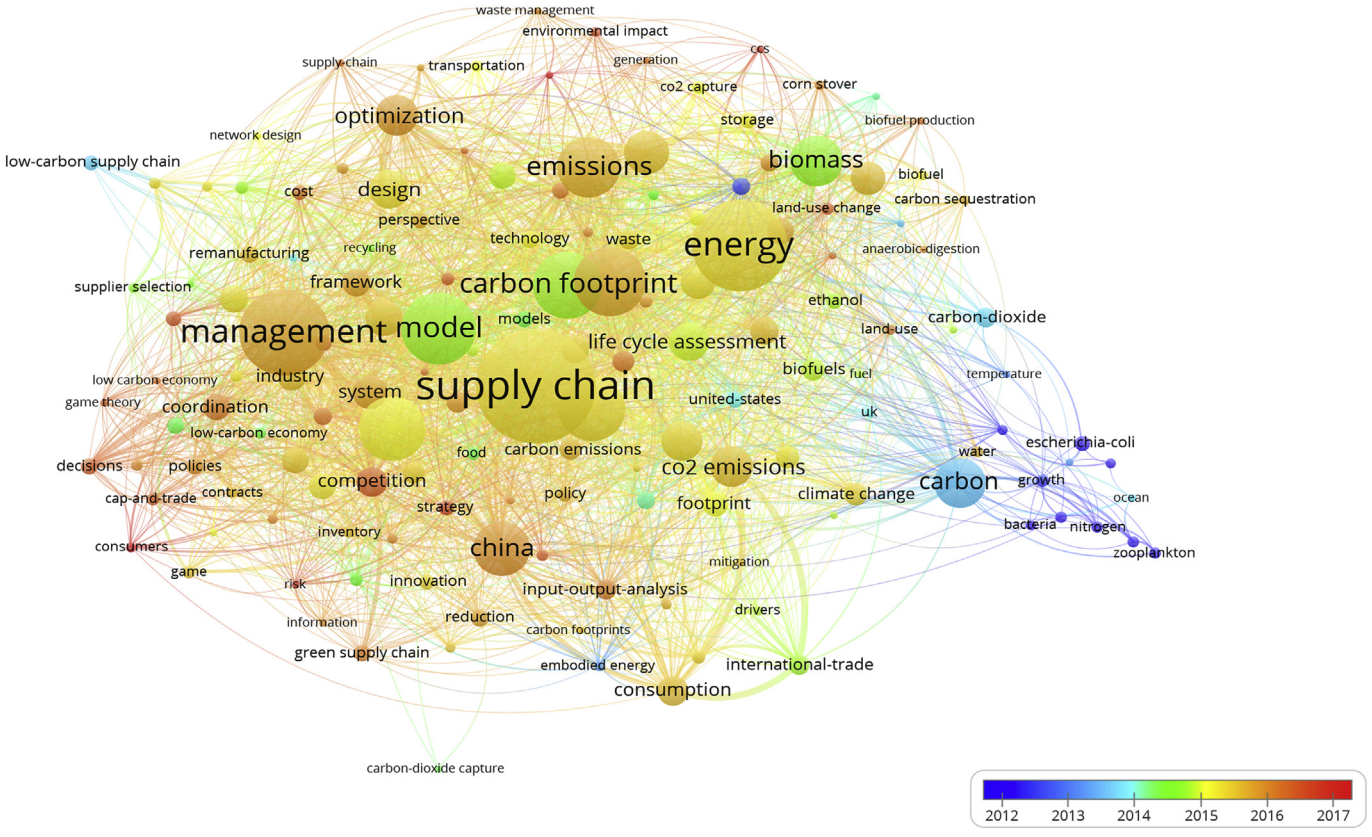


Fig. 3. Overlay visualization average publication per year occurrences - full keywords all fields.

After Step 1 and the selection of databases, Step 2 assigned filter criterion, such as only LCSC as a keyword to be included for searching journal articles, as our approach excludes chapters of book publications. The results reveal that there are 124,793 publications across all research fields and 2199 publications for sustainability and environmental management sciences, including the fields of business and management (labelled as Business & Management Field in Table 2). Moving on to Stage 2, a manual check for double-counted and duplicate papers was made to account for the limitations of the filter options of the databased. Step 1 positioned all publication files into Mendeley, a reference management software. After performing Step 1, the authors ensured that no redundant articles were found for either sustainability or environmental management sciences. Stage 2 for sustainability, business management and environmental management sciences required a thorough inspection and manual filtration by the authors because only topics related to sustainability and environmental management sciences were recognized. The filtration was done while obtaining publications from databases and using Mendeley. The contents are derived from detailed, careful selection based on the previous procedure as recommended by Shaharudin and Fernando (2017). After completion of Stage 2, software analysis was used to analyse the data. In Stages 3 and 4 we analysed the available data using the VOSviewer software for interpretation, development for thematic insight, development of key findings, and reflection on primary research questions.

In sum, Stage 1 was the co-occurrence analysis to identify themes of LCSC based on all collected literature. In Stage 2, the keyword (LCSC) was found within and across various fields. This effort helps the authors to identify the most frequently cited journals and the historical period during which the most publications were produced. Stage 3 helped to identify the gaps in the literature and future research focus for scholars studying LCSC. Stage 4 involves the interpretation of results based on the Stage 3 analysis. The reliability of content analysis depends on adherence to the 4 Stages, consensus among researchers, and experience.

4. Results

Our results demonstrate that Mendeley and VOSviewer are effective tools to cluster the content and themes of publications. With the right techniques, Mendeley can be used as a content filter to determine published keywords and to avoid content duplication. The use of VOSviewer as a tool for content analysis makes the visualization of the clustering content simple and also creates informative infographics. This is an effective tool for identifying the aggregate level of the density of keyword occurrences. The combination of Mendeley and VOSviewer is useful for visualizing gaps in analysis and in finding emerging topics and patterns of research, especially as researchers work with an abundance of data.

Using clustering software such as VOSviewer, this study shows how the visualizations provided by VOSviewer can be used to focus visualizations at an aggregate level to determine the density of keyword occurrence in published works, which aids in analysing

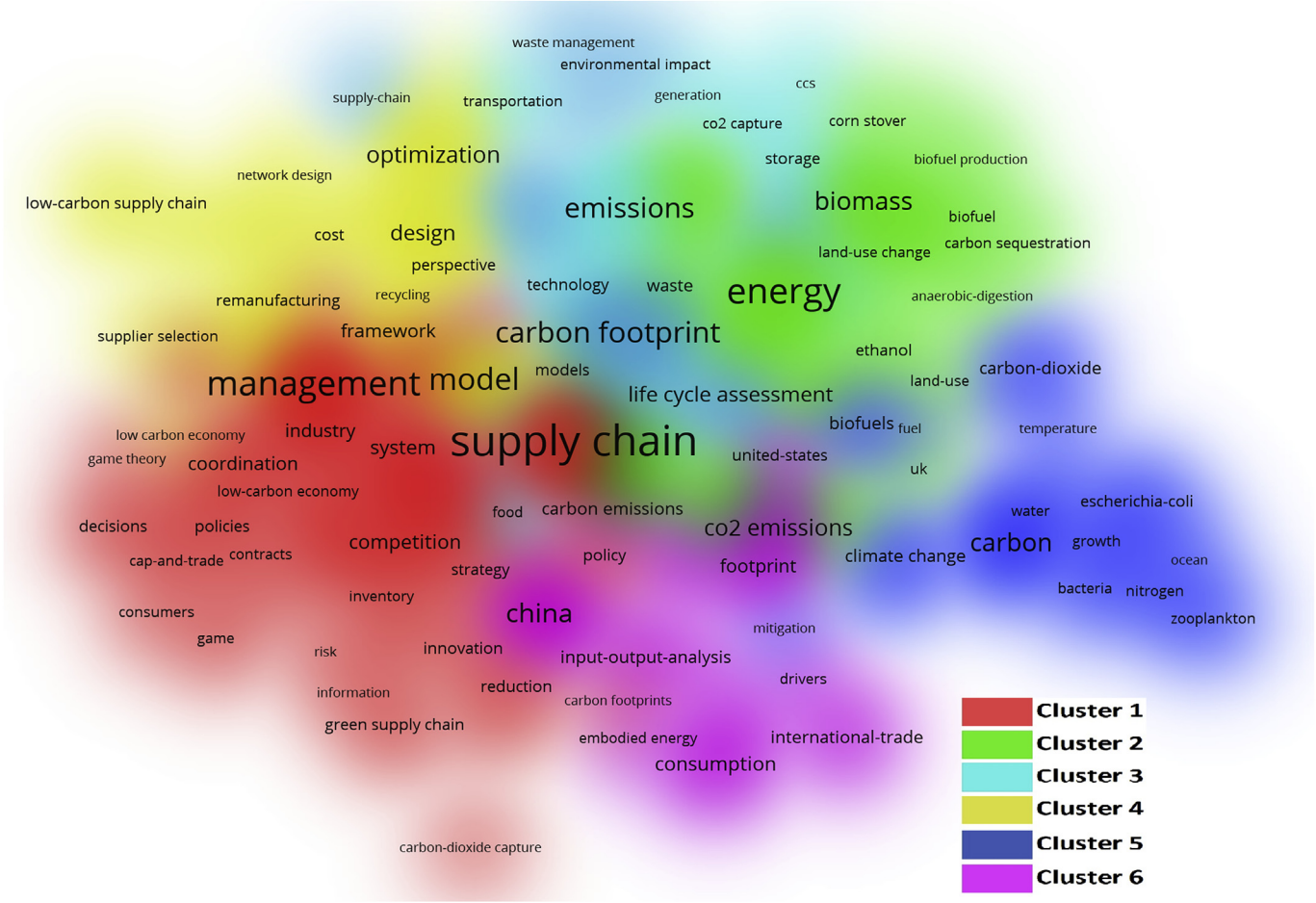


Fig. 4. Density visualization cluster density occurrences - full keywords all fields.

the resulting clustering solution. The dynamics of clusters (displayed in simple, engaging infographics) – which can reveal the density of interest, identify research gaps, and display how trends in a topic have changed over time – is a powerful indicator and reference for future research that scholars have access to and should utilize. This study also notes the advantageous use of these software for finding direct citation relationships. The clustering technique makes it possible to sort data from a large number of publications.

The LCSC topics that are widely discussed in literature cover the research areas of supply chain, energy, research models for management, carbon emissions, carbon footprint, and life cycle analysis. Fig. 2 shows that there are six clusters identified through co-occurrence analysis. These results help to answer primary research Q1 in discovering the main themes related to LCSC. Based on these findings, the most dominant cluster is *supply chain management* (Cluster 1). Thus, *supply chain management* is the main cluster and the most widely discussed keyword in the areas of technology, engineering, and management. This finding is supported by the abundance of LCSC focused studies found in the literature. (Böttcher and Müller, 2015; Luo et al., 2017; Mao et al., 2016; Shaharudin and Fernando, 2015). The second most dominant keyword is *energy* (Cluster 2). Previous studies prove that energy is part of LCSC practices by utilizing content analysis (Wang et al., 2017) and survey-based empirical results (Fernando and Hor, 2017). Therefore, LCSC practices should incorporate energy efficiency targets and low carbon energy sources to help firms reduce carbon emissions, specifically through biomass production (Abdulrazik et al., 2017; Pang et al., 2017; Welfle et al., 2017).

Carbon emissions measurements (Cluster 3) was the next most dominant theme. In this cluster, scholars have given attention to carbon emissions measurements by looking at the carbon footprint and life-cycle analysis. The carbon emissions measurements are discussed in Cluster 3 and linked with energy outcomes (Cluster 2). Cluster 3 was also linked to *LCSC models* (Cluster 4). The LCSC model can be found in previous studies (Huisingh et al., 2015; Kaur and Singh, 2018). The conceptualisation of LCSC is frequently discussed in this cluster. Despite the fact that sustainability and environmental management sciences were the main interest of this study, the *multidisciplinary approach* relating to technology and engineering was widely covered (Cluster 5). Finally, a *technical approach* on managing carbon emissions reduction studies formed Cluster 6.

Emerging studies that incorporate low carbon energy in supply chain management attract attention from a large number of scholars. Our predictions are that this field of study will only continue to grow given an increase in published journal articles from year to year across our data set. Fig. 3 shows the average number of publications per year for LCSC literature and, given the increased size of cluster nodes and the increased amount of connected clusters in yellow and red, indicates an increasing trend from 2017 onwards. Scholars are shifting from investigating low carbon strategies for energy towards implementing low carbon energy in the supply chain. This is evident in the linkage between *energy* (Cluster 2) and *supply chain management* (Cluster 1). Böttcher and Müller (2015) also support low carbon energy as part of the supply chain production process because it is useful in reducing carbon emissions.

In finding answers to primary research question Q4, Fig. 4 shows cluster density of co-occurrences that demonstrates words used,

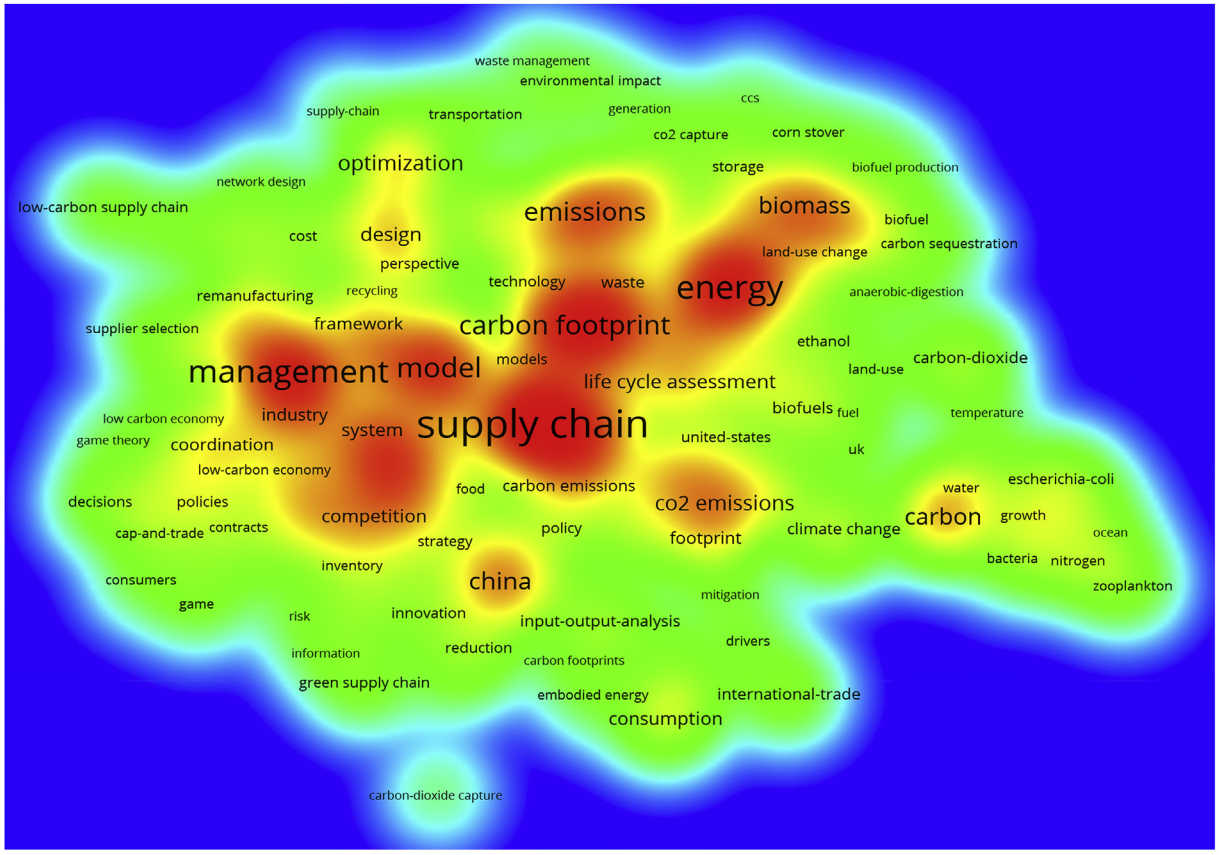


Fig. 5. Density visualization item density occurrences - full keywords all fields.

along with gaps in LCSC literature. The results show that *carbon emissions measurements* (Cluster 3), *LCSC model* (Cluster 4) and other *management studies* (Cluster 6) receive less attention from scholars than the other clusters. The measurement of carbon emissions from the management perspective is growing slowly, with limited publications that include empirical research results. Despite the fact that scholars have attempted to *conceptualise the LCSC model* (Cluster 4), the results reveal less discussion in the business and management research areas. Additionally, limited empirical data is available in the form of surveys on *low carbon performance* (Cluster 3). In Cluster 6, *country-based LCSC* studies focused on several factors. This suggest that country setting, LCSC drivers, policy, strategy, and internationalization are critical issues that need to be included in LCSC studies.

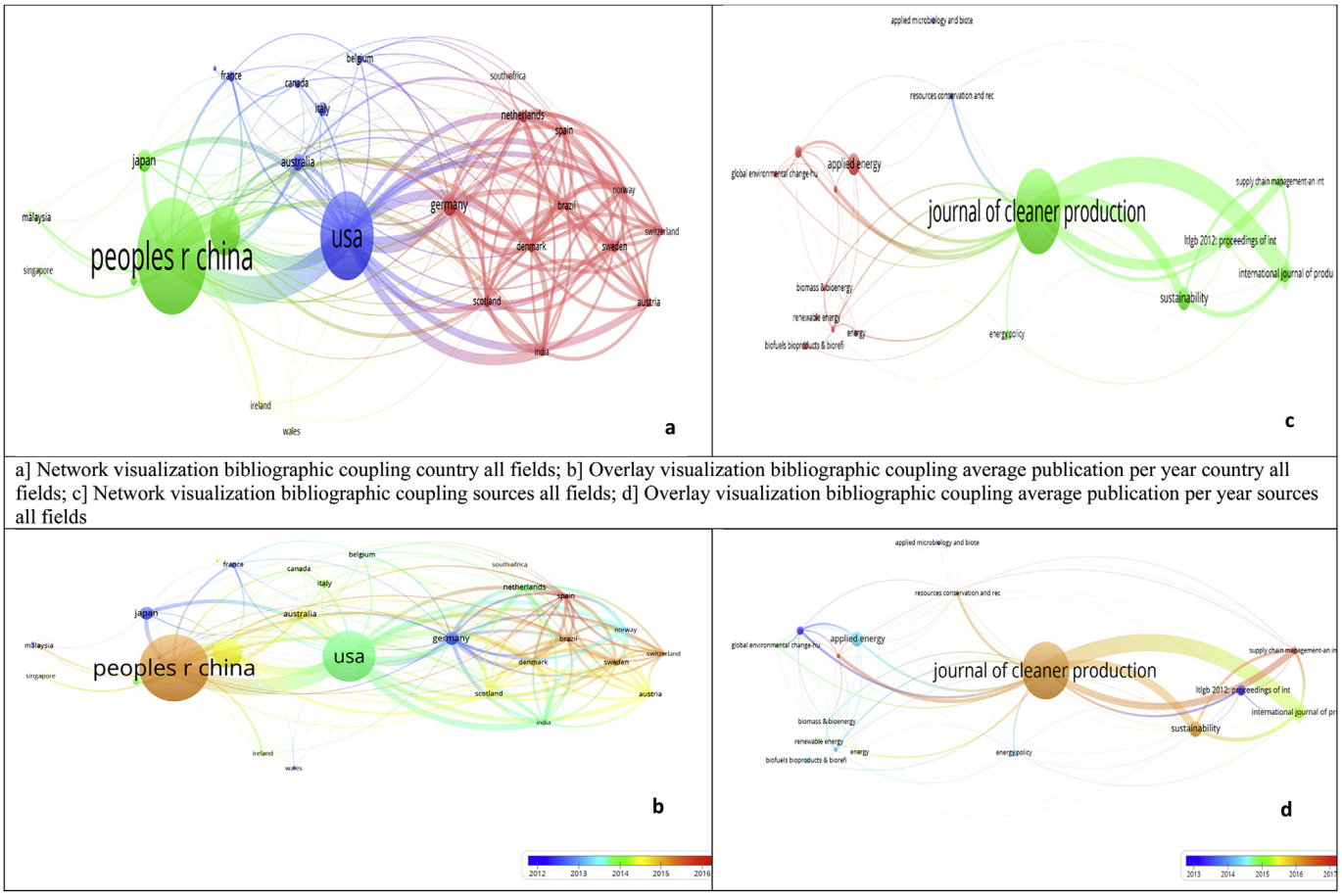
Fig. 5 displays the parameters that define LCSC. In the literature studied, LCSC is associated with supply chain practices, carbon emissions, energy management, optimization of supply chain, carbon emissions measurement, and economic performance. Further, the outcomes of LCSC should improve environmental performance (carbon reduction), operational excellence (productivity, efficiency/effectiveness & supply chain optimization), and economic performance (profit & value added).

To help highlight the origins of LCSC scholarly work, we find answers to primary research question Q3 as Fig. 6 (a) shows the distribution of publications organized by country. China contributes the highest number of LCSC studies followed by the United States and European countries. Additionally, Fig. 6 (b) illustrates that China has overtaken the United States in average publications per year. It also shows that studies on LCSC are increasingly being published in European countries. Nevertheless, American scholars are still considered to be the main contributors to the development of LCSC studies since European and Chinese scholars often cite the findings of many American scholars.

Fig. 6 (c) shows the citations for LCSC and indicates that most of the papers on LCSC were published in the *Journal of Cleaner Production* (Elsevier). This journal is highly referenced and cross-cited in journals such as the *Energy Policy Journal*, *Sustainability* and some technically oriented journals. In this current study, the *Journal of Cleaner Production* was dominant among other sustainability, energy, and supply chain journals including *Supply Chain Management: An International Journal, Sustainability*, and *Resources, Conservation and Recycling* (Fig. 6 (d)).

Fig. 6 (d) shows that citations circulate from the *Journal of Cleaner Production* to other science and social science journals. In fact, the *Journal of Resources*, *Conservation and Recycling* has shown great interest in the LCSC topic and also has a close linkage to other technically based energy journals. Thus, we predict that *Resources, Conservation and Recycling* will develop into a multi-disciplinary platform of LCSC (Fig. 7). Answering primary research question Q2, the current trend shows that the *Journal of Cleaner Production* and *Resources*, *Conservation and Recycling* are contributing to the growth of this research field by accepting LCSC-related studies.

An examination of the business and management science studies focusing on LCSC (Fig. 8) shows that most scholars relate LCSC to sustainability. With a more specific answer to primary research question Q1, the management field associates LCSC with



a] Network visualization bibliographic coupling country all fields; b] Overlay visualization bibliographic coupling average publication per year country all fields; c] Network visualization bibliographic coupling sources all fields; d] Overlay visualization bibliographic coupling average publication per year sources all fields

Fig. 6. Network and overlay visualization of bibliographic.

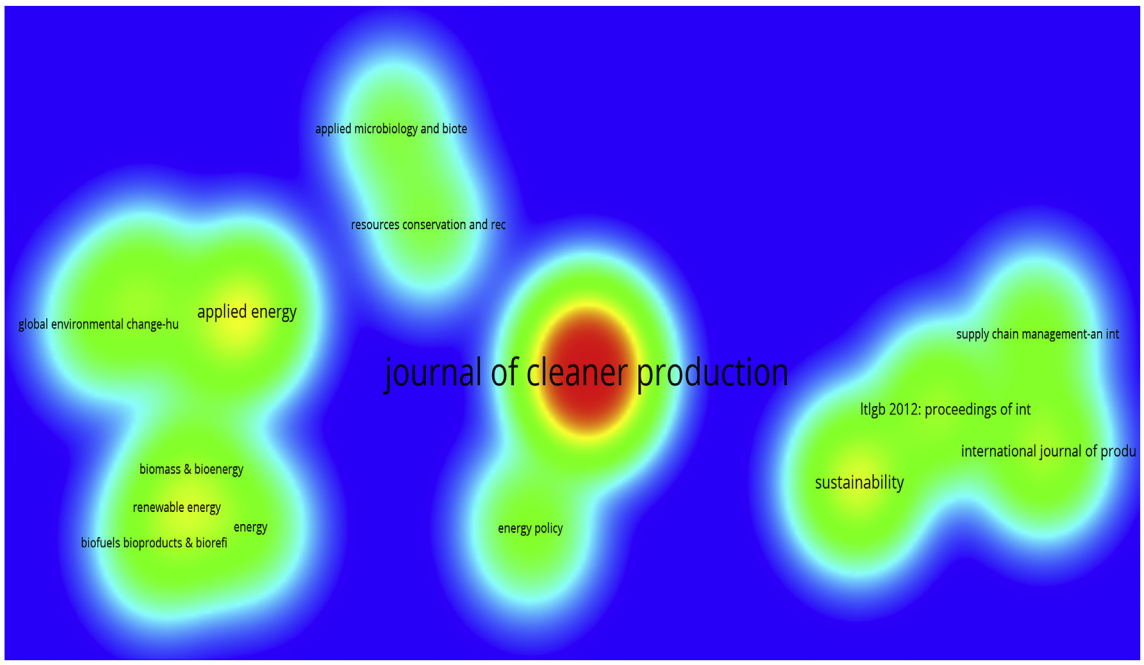


Fig. 7. Density visualization bibliographic coupling item density sources all fields.

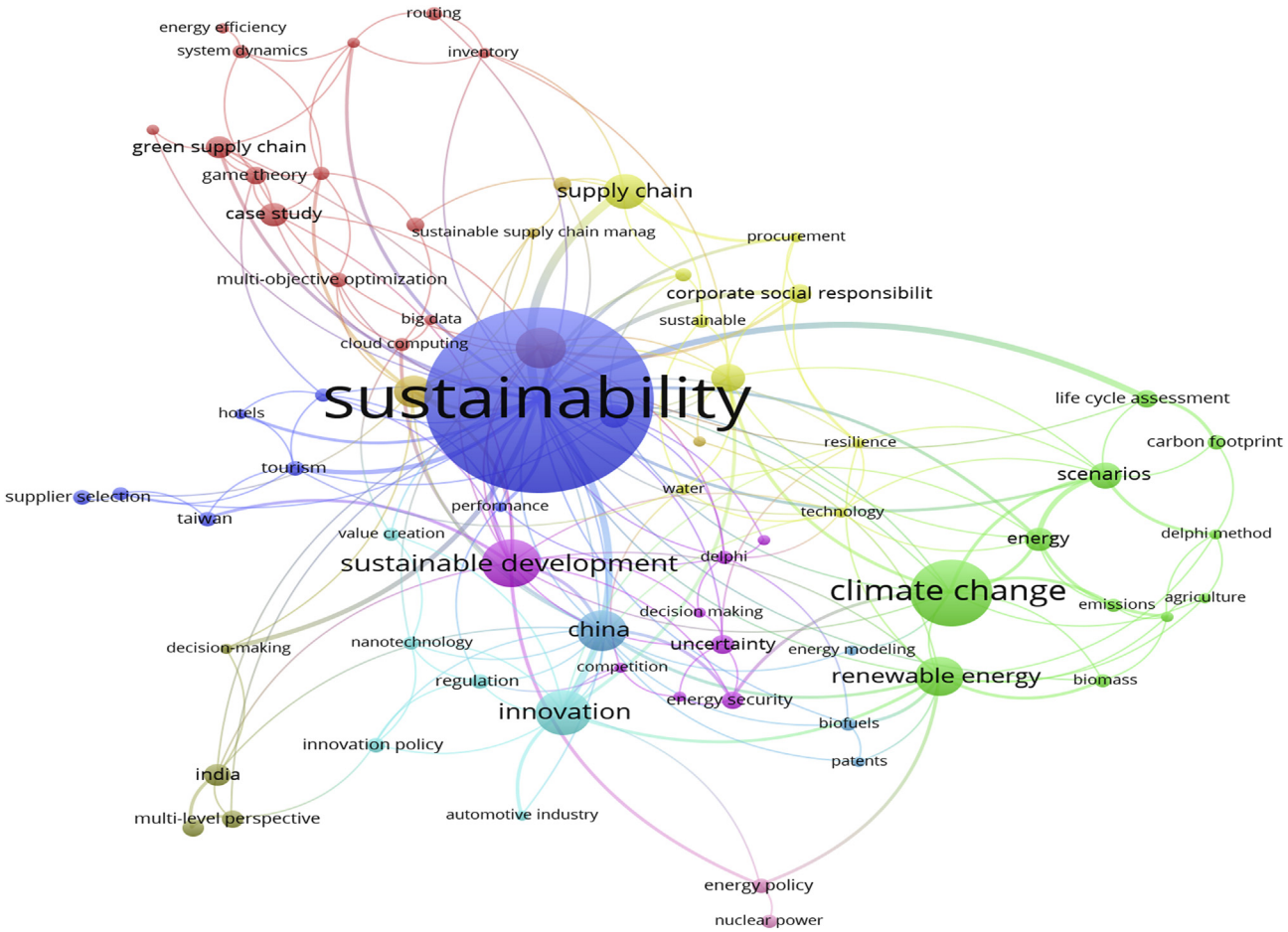


Fig. 8. Network visualization co-occurrences keywords business and management field.

climate change, sustainable development, renewable energy, innovation, and supply chain in the literature. There are seven clusters identified using co-occurrence word analysis. The biggest cluster is *sustainability* (Cluster 1) followed by *climate change* (Cluster 2), *green supply chain management* (Cluster 3), *supply chain management* (Cluster 4), *innovation* (Cluster 5), *sustainable development* (Cluster 6) and *other management approach* issues (Cluster 7).

Sustainability (Cluster 1) is the dominant cluster as LCSC in environmental management studies focuses on the reduction of carbon emissions. One anthropocentric cause of climate change is the high amount of greenhouse gasses especially those originating from carbon emissions. As a result, scholars are investigating mitigation strategies for *climate change* (Cluster 2) through LCSC practices. This leads to scholars defining LCSC within the broader concept of environmental management (Nishitani et al., 2013). Nevertheless, some scholars view LCSC as an element of *green supply chain management practices* (Cluster 3) (Nawrocka, 2008), primarily due to the reduction of carbon emissions as an element of environmental management. The methodology employed in this paper only accepts LCSC as a keyword for publication search. There is no surprise that *supply chain management* (Cluster 4) is one of the main topics for LCSC. However, it is surprising that *innovation and technology* (Cluster 5) is included in LCSC. Investigating the different applications of low carbon technology and green technology would be a suitable topic for future research. Finally, *other management approach* issues (Cluster 7) does not provide insightful information to contribute to filling a gap in the literature and future research at this time.

As shown in Fig. 9, sustainability, renewable energy, supply chain practices, case study research and social performance are current, popular topics of LCSC studies. It is difficult to accurately pinpoint emerging LCSC topics because management science and sustainability scholars are currently addressing the lack of studies for close to every keyword related to LCSC. Information in Fig. 9 supports findings in Fig. 3 which displays increases in annual LCSC publications and we see no slowing of this trend. In finding answers to our primary research question Q4, we find LCSC occurrences and co-occurrence keywords in Figs. 10 and 11. The visualization in Fig. 10 also illustrates that, of any of the topics included in this study, firm *strategy and decision-making* (Cluster 7) paradoxically garners the least attention from management science and sustainability scholars. This conclusion is supported by the limited number of empirical studies available in the literature. Therefore, there is ample opportunity for future research by strategy scholars. Additionally, *energy security and energy policy* (Cluster 6) receive little attention from management approach scholars. This is understandable as energy security and policy can seem far removed from the control of managers involved in LCSC practices. Studies on energy are mostly associated with a technical approach, as shown in Fig. 2. The next lowest density of occurrences is *innovation and technology* (Cluster 5), due to the fact that most technology papers published use the technical approach. Fig. 11 shows that LCSC is part of sustainability and should be discussed further so that it can improve management and business practices. Sustainable development through innovation, renewable energy, and low carbon technology presents greater opportunities to study the impacts of LCSC.

The results of our analysis have provided a wide array of insights and opportunities to answer to our primary research questions.

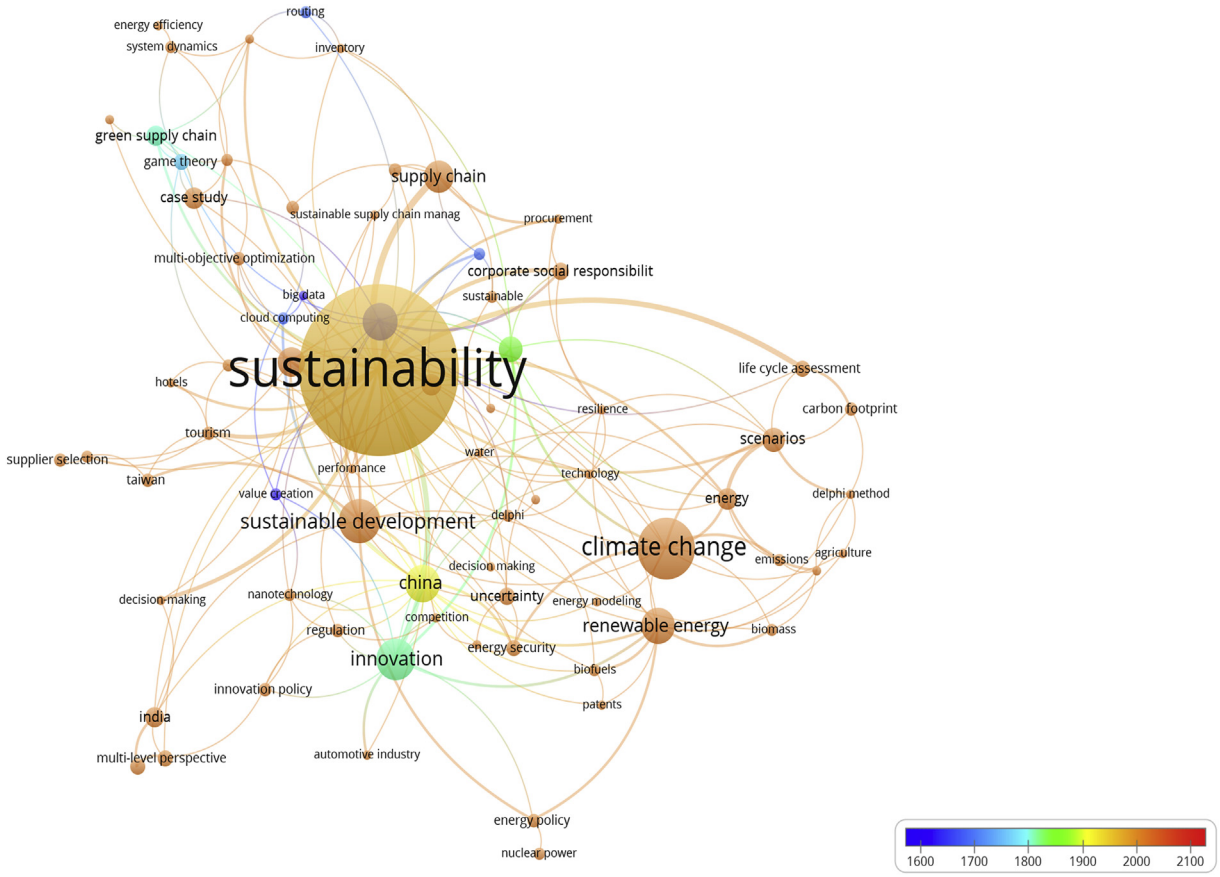


Fig. 9. Overlay visualization occurrences average publication per year business and management field.

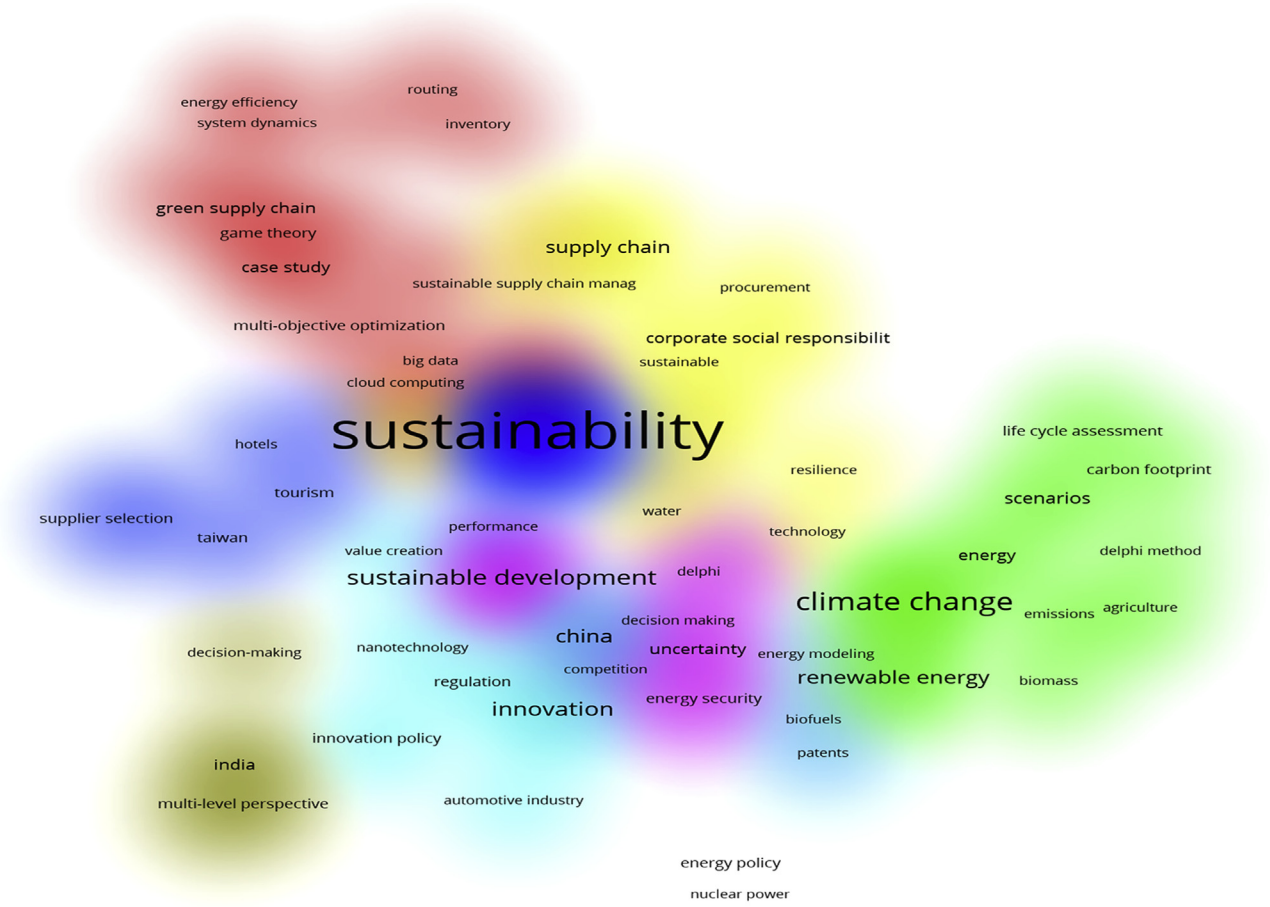


Fig. 10. Density visualization occurrences cluster density co-occurrences keywords business and management field.

There are many benefits to the methods and software used in this study. The main purpose of bibliometric network visualization is to analyse large amounts of complex bibliometric data in a relatively easy way through visualizing core themes in the data. The strength of this approach is in the simplification it provides. Yet, this simplification can come with limitations in the form of a loss of information when textual data is reduced to a co-occurrence of terms and information on the context in which terms co-occur is lost (Perianes-Rodriguez et al., 2016). We can also see who is citing whom, but cannot see why someone's work is being cited. Finally, in terms of distance-based visualization, it may not be possible to position a pair of nodes in a way that perfectly reflects the relatedness of the nodes. With these strengths and limitations of this study and our methods in mind, we next discuss our findings, trends, and future research opportunities before drawing conclusions in section 6.

5. Discussion of the research finding, trends, and future research implications

The results of our analysis have helped us to find answers to primary research questions 1–4. This discussion and the following conclusions section combine to help answer question Q5, and build and understanding of past, current, and future trajectories of the LCSC field of research. Based on the review of current literature, the results of LCSC content analysis using social network analysis has several implications. First, most sustainability papers related to LCSC are published in ScienceDirect databases. The ScienceDirect databases have a prominent role as a publication outlet for the LCSC studies in both natural and social science research clusters. The high impact factor (ranking) of the journals, wide exposure to the targeted audience, and frequent citation attracts scholars to journals published in ScienceDirect before extending a search to other databases.

The citations about LCSC primarily originate from the *Journal of Cleaner Production* (ScienceDirect) and other management and social science journals found in Emerald with coverage in the Web of Science and Scopus. This shows the *Journal of Cleaner Production* remains the major source of references and research for LCSC scholars due to its high popularity and journal ranking. This finding is consistent with other reviews or studies of systematic analysis (Aznar-Sánchez et al., 2018; Wang et al., 2017). However, surprisingly, research on carbon accounting – that measures carbon emissions to help a firm to achieve low carbon performance – is limited in the *Journal of Cleaner Production*. Other key journals such as *Resources, Conservation and Recycling* are shown to have closer linkage with the management, scientific, and technical research approach. A systematic study by Stechemesser and Guenther (2012) has proven that technically related topics for carbon emissions reduction can be found in *Resources, Conservation and Recycling*. This demonstrates that this journal has become a platform for multi-disciplinary studies related to sustainability and will become a major publication outlet for scholars from diverse disciplines in the future. Since 2016, an increasing number of LCSC studies have been published that relate to policies, decisions, waste management, environmental impact, low carbon economy, strategy, and

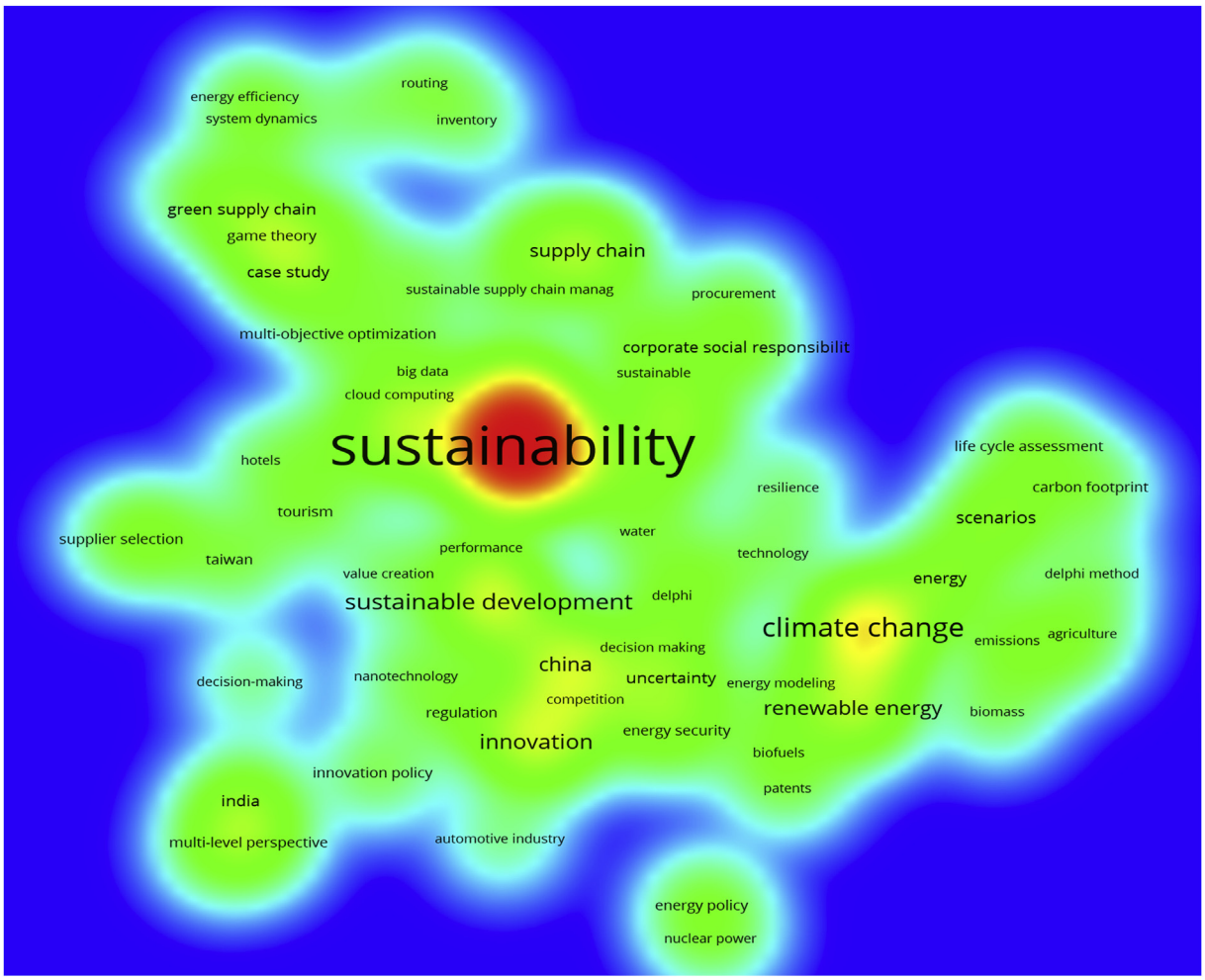


Fig. 11. Density visualization occurrences item density co-occurrences keywords business and management.

risk issues. These concerns are also stated by management scholars in the field of supply chain and operations (Bastas and Liyanage, 2018; Fang and Zhang, 2018; Kuo and Smith, 2018). This emerging trend contributes to the ability to leverage environmental regulations and government involvement in environmental protection, enforcement, and pollution control over the last three years. This has led to an increase in awareness of environmental issues among consumers and other stakeholders.

The current wide range of publications related to LCSC topics encompasses and intersects with the fields of engineering, sustainability, and management science, and indicates a substantial intersection of disciplines. This shows that LCSC research is interdisciplinary in nature. Yet, the consensus to use LCSC as a common measure is still under research. As such, there exists a growing need to extend the minimal investigations on a topic that combines the merits of different research tools (Dubey et al., 2017) and addresses interdependent issues encompassing the entire spectrum (Antoinette et al., 2015) of LCSC, ranging from technological issues and scientific procedural and environmental viewpoints to management issues. A prominent issue of the current analysis shows that a keyword has not yet been defined for the theory that explains the complex relationship of LCSC in literature. This analysis shows that scholars rarely disclose theory used regarding LCSC studies. There is a significant lack of studies relating to the theoretical developments for LCSC as well as empirical studies with supporting theory (Geng et al., 2017).

Environmentally focused supply chain and management science-based studies on LCSC remain popular with scholars. This current study predicts that this pattern will continue in the future given the increased recognition of LCSC in national and industry-wide agendas. This is also supported by Das and Jharkharia (2018a,b) in their systematic review of LCSC. A larger volume of studies will also assist manufacturing firms in improving organizational yields by utilizing sustainably oriented supply chains. This will benefit society at large by strengthening the environmental regulations imposed on firms (Fang and Zhang, 2018). Some factors need to be considered in the future, especially for examining the determinants and outcomes of LCSC. However, in the LCSC business management field, other areas such as costs, information, risk, contracts, transportation, network design, and others should be investigated further in order to develop robust information on the applicability of this concept for practical usage.

This study found that China is the most prominent player in LCSC publications, surpassing the United States in terms of number of publications in the databases analysed. This study postulates that the higher number of publications in China is due to the country's escalating environmental issues in comparison to other countries. Due to its large population, rapid industrial development, and the scarcity of natural resources, China is faced with mounting environmental problems concerning land use, air quality, water conservation, and ecological conservation. Due to these challenges China is among the largest contributors to environmental pollution

(Liu et al., 2016; Zhang and Wen, 2008). However, current environmental policies adopted by the Chinese government and environmental awareness among stakeholders may lead to more environmental research related to LCSC and sustainability issues in China (Huang and Zhao, 2018). The situation is the same for the United States. Current environmental awareness trends may also catalyse an increase in environmental research publications. Nonetheless, it will be interesting to see if other scholars validate the existing findings and improve on the trend of environmental research in China and the United States from their respective countries. This will provide a better understanding of the environmental issues faced by emerging and growth-leading economies (i.e., Brazil, India, Indonesia, Mexico, Russia, and Turkey) from which data and publication research is currently limited.

6. Conclusions

Managing low carbon emissions is an emerging topic in need of specialized skills and attention from managers who understand the environmental issues that relate to supply chain management. Previous studies have focused heavily on industry practices and have revealed a lack of evidence in the discussion surrounding the policy associated with a low carbon campaign. Future studies should aim to integrate energy policy into the research model in order to understand how policy makers can encourage industry to comply with low carbon emission and energy management practices. Despite the growing importance of low carbon energy in supply chain management literature, there is a lack of research that addresses energy policy and sustainability compliance in regard to a country's respective policy and evidence of adoption. Previous LCSC literature pertaining to management and supply chain strongly favours industry-based and carbon emission research, whereas the policy aspect was somewhat overlooked. As policy is related to the adoption rate of LCSC practices among firms, research interest should be focused in this domain in the future. In particular, research that deals with environmental and energy policies needs to be addressed in LCSC studies.

This study demonstrates the capabilities of Mendeley and VOSviewer for clustering publications. Even though this study suggests the ease of use of the software, preparing the data for evaluation is a laborious process and must be done meticulously to ensure good results. Furthermore, researchers should have proper, basic knowledge of reading the output data to interpret the end results and make reasonable conclusions. Finally, this study presents how Mendeley and VOSviewer software may be used for constructing and viewing bibliometric maps. Mendeley and VOSviewer are useful content scrutiny software packages that combine a powerful mapping and clustering technique with an advanced viewer which creates a single, easy-to-use computer software that also generates functional and practical infographics. Mendeley and VOSviewer can be used in future research for bibliometric mapping and clustering techniques to extend the work performed in this study. We hope the methods used in this study will be extended to other fields of research domains and topics.

The contributions of this study include proposing a conceptual model of LCSC based on a review of existing literature. The study's deeper and more systematic review and visualization of this field of research found that LCSC focuses more on supply chain practices and energy management. The LCSC is a complex managerial practice that comprises abundant activities to design, monitor, and control low carbon activities involved in the management flow of goods/services in upstream and downstream chains. LCSC aims to reduce carbon emissions and improve low carbon performance related to business outcomes in multi networks. This research within this study has proposed a conceptual model, multiple relationships between clusters, and gaps in the literature that needs further empirical investigation on energy efficiency and the sustainability outcomes of a firm, especially in the context of emerging economies. LCSC has been associated with low carbon performance, yet more consensus is needed in the literature to prove causal relationships to other dimensions of firm performance. With a continued trajectory of more measurement and improved technology, the involvement of carbon accounting can assist manufacturing firms to record low carbon assessment and achievements of low carbon performance. Measurement, management, and accountability are needed to further advance carbon as part of integrated approaches to future management practices, with many opportunities for multi method empirical studies of this paradigm.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2019.02.016.

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